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Pattern-based Business Model Development for Cyber-Physical Production Systems

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Abstract

The application of Cyber-Physical Systems (CPS) in production systems leads to Cyber-Physical Production Systems (CPPS) or the Smart Factory, respectively. In such an environment products, production resources as well as processes are each individually characterised by the special qualities of CPS. The current and future business potentials of production networks with decentralized coordination are enormous. However it is difficult for companies to keep track of the risks and chances of CPPS and develop appropriate business models. Therefore in this contribution a methodology for the pattern-based development and realization of business models in the context of Cyber-Physical Production Systems is presented. The methodology comprises three main modules that cover the most important aspects of business models for CPPS. In the first module patterns of established business models are gathered and their applicability in the context of CPPS is examined. The resulting library is then extended with patterns explicitly dedicated to CPPS and represents the base for a development procedure model. In the second module the developed business models are assessed with regard to their risks. For this purpose a method to analyse the risks of different business models and the perception of customers is elaborated. The focus of the third module is on the operationalization of abstract business models into company-specific business processes. It contains a design scheme to model value creation networks as well as typical configurations of these networks. The overall methodology is therefore supposed to make the opportunities of CPPS not only available to big corporations but also to small and medium-sized enterprises.

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1. Introduction

At the edge of the 4th industrial revolution manufacturing companies currently face a fundamental change in the nature of their value chains. By combining local information processing and global communication capabilities in products and production systems of tomorrow, new opportunities open up for the architecture of complex systems. With embedded software previously simple subsystems become intelligent objects that autonomously execute tasks, raise events and communicate with other objects via the internet. Already today, such interconnected systems enable improved or novel business processes within the value creation along the product life cycle.

The current and future business potentials of production networks with decentralized coordination are enormous. However it is difficult for companies to keep track of the risks and chances of these Cyber-Physical Production Systems (CPPS) and develop according business models. Accordingly companies require support in the development, risk assessment and implementation of innovative business models for CPPS [1] [2] [3].

Current research shows that most business models can be reduced to recurring patterns [4]. One example for such a pattern is the concept of "Remote Maintenance" of products or production systems. In this case web-based technologies or the "Internet of Things" are utilized to support maintenance processes via the internet and thus improve them.

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Hence a broad pattern knowledge base is the key to exploit the full potentials of CPPS. Based on this knowledge base companies can identify new business models or enhance established ones step-by-step with a structured approach of a pattern-based business model development. The success of such developed business models then strongly depends on the perceived risks of the involved stakeholders. Therefore a detailed analysis and assessment of the risk situation is of outmost importance. Finally it is necessary to implement the theoretical business model into company practice by identifying the required changes of the existing business processes.

For this purpose in this contribution a methodology for the pattern-based development and realization of business models in the context of Cyber-Physical Production Systems is proposed. This methodology addresses the five relevant action fields pattern library, business model development procedure, risk analysis, operationalization and IT tool support. To further specify the problem background, chapter two discusses the special characteristics of CPPS in particular as well as the issue of business model development and risk analysis in general. In chapter three our proposed methodology is introduced by a detailed description of the most important modules pattern library plus procedure model, risk analysis and operationalization. Chapter four concludes with a summary and an outlook to future work required.

2. Problem Background

In this chapter the theoretical foundations for the proposed methodology as well as previous work in the literature are reviewed. In the first section the concepts of Cyber-Physical Systems as well as Cyber-Physical Production Systems are introduced. Subsequently methods of general as well as pattern-based business model development and risk analysis are discussed in more detail and the particular challenges within the context of CPPS are outlined.

2.1. Cyber-Physical Production Systems

Embedded systems are major drivers of innovation for current high-tech products. Via the internet these systems are increasingly connected with each other to merge the physical world and the cyberspace within so-called Cyber-Physical System (CPS). Supported by sensors these systems obtain information from their physical surroundings and provide them to internet services, that in turn can directly affect the physical world by actuators. CPS are part of a globally connected world where products, devices and objects interact beyond classical application boundaries and form the internet of things, data and services [1].

The application of CPS in production systems leads to Cyber-Physical Production Systems (CPPS) or the Smart Factory, respectively. In such an environment products, production resources as well as processes are each individually characterised by the special qualities of CPS. The resulting potential benefits are manifold [2]:

- Optimization of production processes, where the individual units of a CPPS know their application areas, configuration possibilities as well as production constraints.
- Optimised product customization by an intelligent composition of individually suited production systems under consideration of objectives as product properties, costs, reliability, deliverability, etc.
- Resource-efficient production by minimizing overhead costs and flawed resource allocation.
- Human-centred production processes, where the machines follow the workers' speed and instructions.

This paradigm change associated with CPPS, which is also referred to by the term Fourth Industrial Revolution, thus not only includes a further increase in automation but also the development of intelligent observation and decision processes. It enables the management and optimization of companies and even whole value chains in almost real-time. For the first time the unfinished product takes over an active role during its production: not a central control system but each part for itself determines which manufacturing process steps need to be conducted next. The product thereby controls its own production process autonomously, observes the relevant environment as well as process parameters by its sensor systems and triggers the according countermeasures in case of any disturbances [3].

Due to these new and unprecedented characteristics of CPPS the decision makers in industry and politics are unsure of how to exploit the new potentials in the best way. As CPS interact with each other beyond any company borders and control their own production process, the resulting value of the product can no longer be assigned to one single owner. It is instead necessary to identify new forms of collaborative product development and production between companies of the same or different value chains. New business models are therefore required to widely facilitate the benefits of CPPS.

2.2. Business models and recurring patterns

A unified description of the structure and the content of a business model can hardly be found in literature. Various definitions take different aspects into account, e.g. the value proposition, the process for creation of goods etc. In comparison to a strategy, a business model encompasses single aspects that are crucial for the value add for the customer. Goal is a holistic characterization of the business and simultaneously the reduction to the essentials [4] [5] [6] [7] [8].

From the different definitions can be deduced, that business models encompass many facts. For reducing complexity and giving a sound overview, an approach for a clear structuring is needed. Therefore, Osterwalder and Pigneur developed the "Business Model Canvas", which comprises eight parts surrounding the value proposition (i.e. customer segments, customer relationship, distribution channels, key partner, key activities, key partnerships, revenue streams and cost structure). Chesbrough separates his business model in six parts (i.e. value proposition, target market, competitive strategy, value chain, ecosystem and profit model). Furthermore, there are approaches from Bieger et al. or from Johnson, Christensen and Kagerman worth mentioning [6] [9] [10] [11].

The structural parts of the different approaches reveal recurring patterns in the theoretic models (e.g. value proposition or resources) and in practice as well. Those business model patterns are aspects of a business model, that repeatedly appear in different areas and branches. A common example is the pattern "Freemium" that originates from the e-Commerce. Here basic services are free, premium services are priced. Those patterns can be transferred into existing or new markets and therefore be recombined. Some patterns can be found in literature [4]. Nevertheless, patterns for CPPS are barely analysed or even described. In summary, while general business model pattern are partially described, an approach for a pattern-based business model development is needed.

The business model generation is based on the strategy development. Successful business models encompass three aspects: accordance with corporate objectives and business strategy, internal consistency of the aspects and robustness against competitors [6] [12] [13] [14].

Different approaches within the business model generation are based on patterns or pattern-like models. Most are generic proceedings detached from specific industry or technology, focusing designated aspects of the business model generation. Boulton et al. are focusing the value creation through using the assets of a company [15]. Linder and Cantrell describe an approach based on existing business models – they are focusing the core activity of the company and the price-performance ratio [16]. Voelpel et al. developed a method for disruptive business model innovations considering both, the market and the technology perspective [17]. Osterwalder et al. are using market changes to develop and implement new business models, while especially financial aspects are focused [18]. Following this idea, Osterwalder and Pigneur generalised the approach with the Business Model Canvas [6]. All these approaches describe a general approach for developing business models. Additionally, some specific methodologies exist for selected branches, technologies or topics. In summary, existing approaches for the business model generation are mostly universal and generic, whereas specific approaches focus selected areas (e.g. e-Business). For the complex area of CPPS a comprehensive approach for developing business models is missing.

2.3. Risk Analysis

A central component of a business model is the risk distribution between the involved parties [19]. This risk distribution varies between different business models. Innovative business models as those of CPPS are often characterised by a high degree of collaboration as the supplier is involved in the customers processes [20]. The engagement with the customer entails higher risks on the supplier's side compared to pure product businesses [21]. Furthermore collaborative business models result in a high degree of coordination between the involved parties which induces additional risks resulting from the dependence on the other party. Suppliers have to consider this higher risk taking in their pricing and customer are faced with the challenge to assess the benefits of the CPPS against the higher price.

Meanwhile risk perception highly differs among individuals [22]. Hence, also the evaluation of business models is dependent on individual factors. Especially in cases of long lasting contracts the actors are confronted with high uncertainty as most of the risks are really difficult to predict. In case that the risk perception is different between customer and supplier a cooperation might fail, because the supplier requires a higher price for the risk assumption than the costumer is willing to pay. Hence, it is necessary to individually assess every potential partner. Currently the individual risk perception of customers and suppliers in business models is not a subject of research. However the management of a business model is significantly influenced by the individual risk perception. Therefore the supplier should be familiar with the risk assessment of his customer. Since up to this point there is no methodology dedicated to the development, risk analysis and operationalization of business models in the context of CPPS, in the next chapter our according approach is presented.

3. Methodology for the pattern-based business model development

The methodology that is presented in this chapter is basically composed of three main modules that are presented in the following sections. Additionally it is intended to support the according procedures and methods of these modules with an IT tool that guides the users iteratively through the development, risk analysis and operationalization of their individual business models. Due to the conceptual state of the methodology, the specification of the software tool is not further considered within this contribution.

3.1. Pattern-based business model development for CPPS

The development of business models is based on a success promising business idea and the consistent combination of single aspects of the business model. Recurring patterns are the starting point for the development and assessment of business models. Therefore, existing patterns need to be collected and evaluated.

Figure 1 illustrates the concept of business model patterns in the context of CPPS, where patterns specify the generic collaboration of different defined roles within a business model. Most patterns address particular kinds of business relationships, e.g. between logistics and customers or between suppliers and factory operators. However especially CPPS patterns are more comprehensive in nature and address the whole product engineering process. Therefore they include value creation shares of all roles within the CPPS, i.e. from product developer and producer to customer.

Hence, knowledge about generic patterns is as important as about specific CPS/CPPS patterns. Comprehensive research already leads to resulting patterns from well-known business models (e.g. "Razor and Blade"). These information are gathered from partner companies, literature (e.g. Gassmann et al.) and databases. The analysis of detected patterns results in a detailed classification scheme for business model patterns which is also relevant for CPS/CPPS patterns. According to this classification, new CPS/CPPS patterns can be elaborated, analysed and stored in a pattern library. For this purpose workshops and interviews are performed with participants from academia and industry. With an influence analysis, the compatibility of patterns are examined. Therefore all identified patterns are assessed pairwise, whether they complement or even obstruct each other. The result of this assessment are "chains of reasonable combinations" of different patterns. The assessment is not company or industry-specific, i.e. it is evaluated detached from existing business models.

Subsequently, an impact assessment of CPS/CPPS patterns gives hints on changes they will cause in business models: Which aspects of a business model need to be changed if a specific CPS/CPPS pattern is used? This analysis leads to adaption mechanisms for business models. For instance, remote maintenance is based on web-technologies. Therefore if a company wants to offer remote maintenance, the according web-technology competences will have to be acquired first. Based on these results business models can then be deduced. The whole process consists of three basic steps that are based on consistent patterns and a business idea.

In the first step, the business idea needs to be elaborated and evaluated. In a multistage relevance analysis CPS/CPPS patterns are selected, that are most promising concerning the business idea. Regarding the impact analysis, necessary resources, partners, competences etc. can be derived, that are crucial for implementing a pattern into existing business models. Results of the first step are business ideas and suitable patterns as well as necessary competences or resources, respectively.

The evaluation of business ideas as second step takes existing competences, resources etc. into account and compares them with required aspects of the business idea. This comparison reveals gaps as well as commonalities which help assess the business ideas concerning their strategic fit, accessibility etc. The results of the second step are selected and promising business ideas and the required actions (e.g. establish strategic competences).

In the third step the specific business model is elaborated from the business idea. A successful and competitive business model requires a smart combination of patterns. The business idea and the associated patterns are used and enriched with further patterns. This can be done using a hierarchic combination analysis. This method allows a synthesis of a business model based on a pattern that is characteristic for the business idea and subsequently adding suitable patterns. The previous influence and impact analysis helps match consistent patterns. The result is a business model that is composed of consistent patterns, arranged around a characteristic pattern deduced from the business idea.

Thus, a consistent and competitive business model can be derived step by step. Starting with business ideas, suitable patterns are selected. Using a gap analysis the most promising business idea is selected. The arrangement of suitable patterns leads to a comprehensive business model – built from generic and CPS/CPPS specific, recurring patterns.

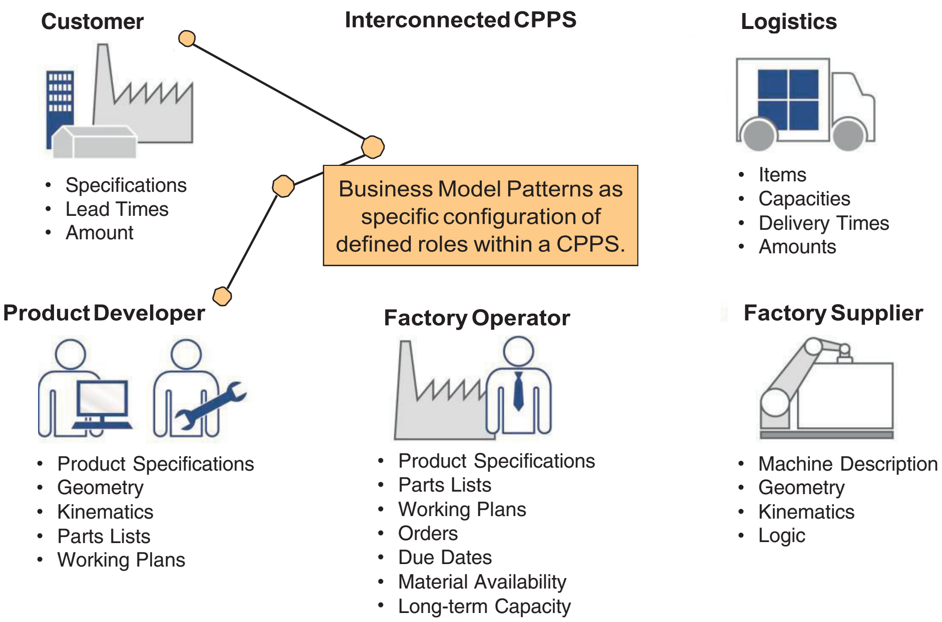

Fig. 1. Concept of business model patterns in the context of CPPS based on Geisberger and Broy [1].

3.2. Risk analysis of business models

Another important aspect of business models is the awareness of all kinds of risks that are taken by the supplier and the customer. Risks can be distinguished between internal, external and cooperation risks.

Internal risks result from the companies' participation in the market per se. The selling of products and services as well as the production processes themselves include a wide range of risks. On the one hand there are risks associated with the technology and the physical parts of the system. Unpredictable failures, component life, retrofitting, upgrades or obsolescence represent some examples for such risks. On the other hand a company's human performance might include risks like misuse or mistakes. Also factors like the organizational structure and the financial strategy add to internal risks [23] [24].

Environmental risks, changes in the regulatory framework and market risks describe external risks [23]. These external risks cannot be influenced by the actors.

Above that co-operational agreements as CPPS create additional risks, so-called cooperation risks [23]. These occur due to the interdependencies between customer and supplier [23]. Link argues that cooperation risks result on the one hand from information and communication [25]. This can e.g. be insufficient information flow or missing transparency. On the other hand cooperation risks can result from different values among the partners, e.g. little trust in the partner, little top-management commitment or different management principles.

Depending on the chosen business model all these risks are distributed differently between customer and supplier [19]. In principle the more responsibility the supplier takes over, the more risks he takes over. In a traditional business models the supplier sells a product (e.g. a machine) to its customer in a single transaction. Due to this transaction-based business model he bears all the risks during the manufacturing of the machine. With the disposal of the product the risk passes over to the customer.

The customer uses the machine and is responsible for all connected processes e.g. the performance of employees. The other extreme are build own operate (BOO) models. In these models the supplier takes over design, construction as well as operation in its responsibility [26] [27]. Hence, the supplier takes over the operation risks and eventually even market risks from its customer if the revenues are tied to the number of units sold [19]. Between these two extremes risk distribution varies.

These risks taken over by the supplier have to be taken into consideration when pricing the offering [28]. However setting prices too high, the supplier will probably price itself out of the market. Hence, suppliers offering CPPS need effective risk evaluation skills. At the same time customers are faced with the challenge to weigh the benefits of the CPPS against the additional risks due to the cooperation and the higher price. When designing a business models for the customer the supplier should be aware of the risk evaluation of its customers, to choose an appropriate business model, manage the relationship over time and to set prices accordingly.

A method to analyse the risks of different business models and the perception of customers is still missing. To develop such a method two major steps have to be taken:

At first an identification of the specific risks connected with different business model patterns is needed. Therefore in-depth interviews with companies offering CPPS will be conducted. In these interviews the distribution of internal risks as technical risks and external risks as market risks will be assessed. Additionally the points in which cooperation is necessary and the critical information and communication flows are identified. The more cooperation is needed by a specific business model pattern, the higher are the cooperation risks that arise.

Secondly an evaluation of the perception of these risks by the actors is necessary. Risk perception depends on a variety of factors. Literature for example identified that the importance of the purchase as well as the complexity of the offering are influencing the perceived risk [29]. Also characteristics of the persons involved and their interrelationships were found to influence a purchasing decision [30]. In the context of CPPS it is assumed that four groups of factors influence the risk perception:

- Characteristics of the individuals involved in the purchasing decision, e.g. individual risk aversion
- Characteristics of the companies involved in the purchasing decision, e.g. company culture, strategic importance of the decision, length of relationship between customer and supplier
- Characteristics of the offering itself (of the CPPS), e.g. complexity, intangibility
- Environmental influences, e.g. competitive intensity

To identify how these factors influence the risk perception, several experiments are conducted. Different business model alternatives are presented to practitioners by means of conjoint analysis. In parallel practitioners are questioned about their individual characteristics, company's characteristics and environmental influences. Additionally they are asked how risky they perceive the different business models. By this it can be analysed under which conditions the participants prefer which business models. The results may suggest that customers perceive higher risk if the decision is important for their company and the offering is complex. Also factors diminishing risk perception may be identified, as for example long-lasting relationship between customer and supplier.

3.3. Operationalization of business models

After a business model has been developed and its qualification regarding the perceived risks of the involved stakeholders was analysed, the implementation from the abstract business model into company-specific business processes has to be performed. For this purpose a design scheme for modelling holistic value creation networks is proposed. To support users in the operationalization the design scheme is complemented by generic shape classes in which value creation networks can occur. The design scheme together with the generic shape classes is intended to explicitly consider the interdependencies between business model and value creation network. Both of these aspects are described in the following sub-sections.

Design scheme for modelling value creation networks

A value creation network is the foundation for an implementation of business models into practice. It comprises the processes and organizational units that are involved in the value provision as well as their interdependencies in a sector-spanning value-added system. These interlinked business processes need to be aligned with all aspects of the business model and have to be consistent with each other to ensure the competitiveness in the market and thus enable a sustainable business performance in the long run.

To accomplish this objective all processes as well as their interdependencies have to be continuously refined over the course of planning, which involves the range from company-spanning value creation processes to company-specific working procedures. However, interlinked business processes are riskier the more interconnected they are. Especially customer-influenced shifts of value creation shares from one organization to another are typical events of CPPS business models and highly affect the risk distribution within the network. A well-defined holistic model of the value creation network is thus also required to identify appropriate countermeasures for potential risks.

The proposed design scheme enables companies to derive their required business processes from the business model and connect them in a suitable value creation network. To fulfil this task the three main components of the design scheme are as follows:

- The Design Space defines the area of valid solutions for a value creation system. Based on the available information any value creation system starts as principle solutions and is refined with every iteration. The Design Space comprises three dimensions: General to Detailed (e.g. branch, company, production system), Abstract to Specific (e.g. organizational unit, process, resource) and Views (e.g. structure, behaviour, shape).
- The Modelling Technique is used to represent the design space as computer-integrated model. In this context established techniques for the modelling of business processes are adapted to enable modelling in different levels of detail and represent all relevant interdependencies between the involved companies in the value creation network.
- The Procedure Model leads the user of the methodology from the definition of the business model requirement to the deduction of the required business processes. Hence it integrates the described Design Space as well as the Modelling Technique in a continuous work flow and comprises the whole process of operationalization. It is thereby the guideline for the implementation of the Design Scheme in a software tool.

Business-model-specific configuration of the value creation network

The proposed Design Scheme is the foundation to model various configurations of value creation networks with differently high degrees of interconnectedness. Typical shapes are for example:

- Research & Development joint venture between competing companies on the same value creation level
- Classical system assembly of an OEM (Original Equipment Manufacturer) that is provided with modules by suppliers just in sequence
- Manufacturing of individual products with lot size one that autonomously seek their way through a company-spanning production system

The identification of a suitable network shape for an elaborated business model requires two basic tasks. At first generic shape classes in which value creation networks can occur have to be identified, specified by means of the previously described Modelling Technique and stored in a shape library. This procedure facilitates the re-use of the generic shape class information and increases the company agility in reacting as response to dynamically changing customer requirements. For this purpose criteria are defined to characterise the generic shape classes of value creation networks and a library is specified for the documentation of the shapes.

Secondly based on the defined generic shape classes and the structured aspects of a business model a consistent value creation network is derived with regard to the customer requirements. In this case special attention is paid to the information structure and hierarchy, so the user can perform a semantic search for suitable generic shape classes that match the specified business model. Additionally a quantification of the compatibility level between the generic shape classes and the business model patterns is analysed to enable a further automated selection process as well as a consistency analysis.

4. Conclusion and outlook

The underlying concepts of Cyber-Physical Production Systems or the Smart Factory mean a fundamental paradigm shift for producing companies. Not only are the products themselves becoming more and more intelligent, but also rise complexity as well as potential risks of the required factories and value creation networks. Companies therefore face new challenges to preserve their competitive advantages in the future. To reduce the barriers within companies that emerge with the exploitation of new and risky business potentials, a methodology for the pattern-based development, risk assessment and operationalization of business models for CPPS has been presented in this contribution. The challenges and methods that are associated with these three aspects of business model development and realization have been outlined and clearly motivated the need for a holistic approach.

While it is obvious that a library of proven business model patterns makes it easier for companies to step up to this whole new kind of competitive collaboration, the acceptance of such a library strongly depends on the quality of the identified patterns. Simultaneously the analysis of the decision makers' risk perception as well as potential configurations of future value creation networks requires qualified input from practitioners to be able to derive valid statements.

Hence, the success of the proposed methodology does not only rely on a structured scientific approach but also on the experience and intuition of experts that know their business and also dare to look beyond. With that in mind it is intended for the future to improve the accessibility of the methodology for companies by developing a software-based prototype that automatically guides the user through the relevant planning aspects. Since the fewer barriers companies have to face, the faster they can adopt the new opportunities that CPPS are able to provide not only for big corporations but also for small and medium-sized enterprises.

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